LA-UR- 93-2040

Title: POLARIZATION DIAGNOSTICS AND OPTICAL PUMPING DEVELOPMENT FOR OPPIS AT LAMPF

JUN 04

Author(s): D. R. Swenson
D. Tupa
R. L. York
M. Dulick
O. B. van Dyck

Submitted to: International Workshop on Polarized Ion Sources and Polarized Gas Targets

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Los Alamos
NATIONAL LABORATORY

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the University of California for the U.S. Department of Energy under contract W-7405-ENG-36. By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy.

Form No. 836 R5
ST 2629 10/91

POLARIZATION DIAGNOSTICS AND OPTICAL PUMPING DEVELOPMENT FOR OPPIS AT LAMPF

D.R. Swenson, D. Tupa, R.L. York, M. Dulick, and O.B. van Dyck
Los Alamos National Laboratory, MP-5, H838, Los Alamos, NM 87544

ABSTRACT

We report improvement of the polarization diagnostics and their use in the development of the Optically Pumped Polarized Ion Source (OPPIS).

INTRODUCTION

We have developed an improved low-energy polarimeter (LEPO) based on the reaction ^{6}Li(p,^{3}He)^{4}He at 750 keV[1,2]. The unique features of the polarimeter are the use of permanent magnet momentum analysis[3] to separate the reaction products from the elastically scattered protons, and the use of both ^{3}He and ^{4}He data to determine the polarization. The polarimeter has been used in source optimization studies. We have continued development of Faraday rotation diagnostics for measuring the alkali vapor density and polarization. The improvements include new calculations and improved technique. We have studied the effect of the laser spectral distribution on the beam polarization.

LOW ENERGY ^{6}Li POLARIMETER

The LEPO polarimeter allows the nuclear polarization of the beam to be measured without using scarce and expensive accelerator time. LEPO operation requires resolving the ^{3}He and/or ^{4}He reaction products in the presence of a much larger background of elastically scattered protons. Past attempts using silicon surface barrier detectors with energy resolution or coincidence techniques have suffered because the electronics were not fast enough to handle the background rate. We have solved this problem by adding a permanent magnet momentum filter to the detection system as shown in Fig. 1. The momentum filter consists of a pair of 2.54-cm-long SmCo magnets with a peak field of 6.7 kG and a gap spacing of 3.0 mm. The integrated field along the particle trajectory (measured to be 15.7 kG·cm) deflects the 750-keV protons by 4.7 mm while the 2.4 MeV ^{4}He and 3.0 MeV ^{3}He (which have nearly the same momentum) are deflected by 2.6 mm. Two collimating slits (1.0 x 2.4 mm) reduce the spot diameter to 4.3 mm at the detector and define the scattering angle. A third slit transmits the He while blocking the protons.

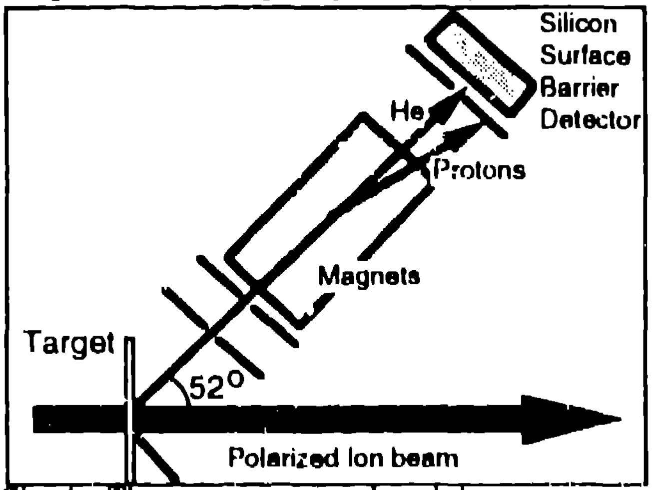

Fig. 1. The momentum analyzed detector system for the LEPO polarimeter.

Figure 2 shows energy spectra with and without momentum analysis. In the latter case, both the ^{4}He and ^{3}He peaks are clearly resolved and can be used to calculate the polarization.

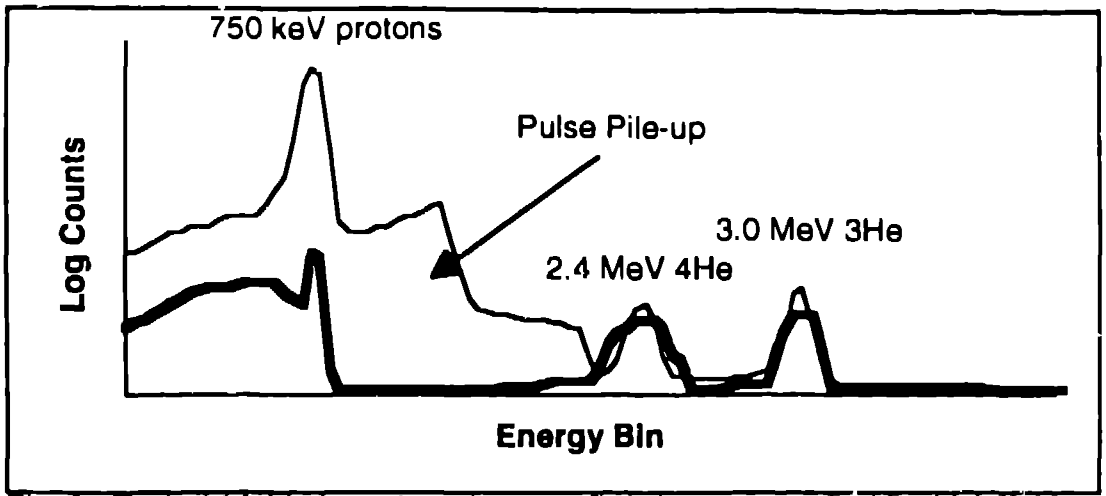

Fig. 2. Typical Multi-channel Analyzer (MCA) data measured with (thick line) and without (thin line) momentum analysis.

Indeed, it is possible to measure the polarization using only one detector and the ratio of the two peak areas. For our experiments, two symmetric detectors mounted at 52 degrees above and below the beam were used to detect forward scattered particles. The polarization can be determined using the conventional "ratio method" using spin reversal with the two detectors and either the ^3He or ^4He data[4]. If the polarization is the same in both spin states, the ratio of the analyzing powers for the two reactions can be determined[5]. Another way of determining the polarization uses data from both peaks on both detectors, the "four peak method". The four peaks can be used to form the ratio:

$$R = \frac{N_{u3}N_{d4}}{N_{u4}N_{d3}} = \frac{\Omega_{u3}\Omega_{d4}}{\Omega_{u4}\Omega_{d3}} \frac{(1+\alpha_3 P)(1-\alpha_4 P)}{(1+\alpha_4 P)(1-\alpha_3 P)} = R_0 \frac{(1+\alpha_3 P)(1-\alpha_4 P)}{(1+\alpha_4 P)(1-\alpha_3 P)}, \quad (1)$$

where N is number of counts, Ω is the detector acceptance solid angle, α is the analyzing power, P is the beam polarization, and R_0 is R measured with unpolarized beam. The subscripts distinguish between the ^3He or ^4He peaks on the "up" or "down" detectors. The quadratic equation can be solved for P as a function of R/R_0 and the known analyzing powers. This method allows the polarization for each spin state to be determined independently, and it is less sensitive to changes in the false asymmetry or beam steering. The different methods provide cross checks to limit systematic errors. Experimental results using these methods are discussed below.

LEPO RESULTS

Results with the momentum analyzed version of LEPO are encouraging, although improvements are needed. The most serious problem was the limited lifetime of the targets. The targets consisted of 120 $\mu g/cm^2$ of ^6LiF evaporated onto a 40 $\mu g/cm^2$ carbon foil. To achieve a lifetime of a few days, it was necessary to limit the average beam current to 0.5 μA. Count rates for each peak were typically 1 count per second per μA. The proton background rate was 5 times larger. Count rates were sensitive to the beam steering. The beam had to be positioned precisely to get equal rates in the two arms, which indicates that the alignment was not ideal. One would expect the ratio of the ^3He and ^4He peaks measured with one detector for unpolarized beam would be constant because the momentums are nearly the same and hence the Ω's should be the same. If this were so, with proper alignment, R_0 would equal 1 and would not need to be measured. This was not always the case, indicating possible misalignment of the detectors or problems with the target. Measurements taken during one-day indicated that R_0 did not drift. For example, during a one day run with unpolarized beam, five measurements of P yielded a standard deviation of 0.9%, in agreement with the counting statistics. However, from day to day, measurements of R_0 ranged from 0.81 to 1.02. More study of the systematic errors is needed. Using the measured R_0, the "four-peak method" gave consistent polarization measurements.

LEPO was used in source optimization studies. The measurements showed better polarization with a 7-hole extraction lens (3.3-mm-diameter ion beam) than with a 19 hole extraction lens (4.3-mm-diameter ion beam). The polarizations were 69±2% versus 63±1%, which agreed well with later measurements at 800 MeV. A tubular μ-metal shield was installed around the zero-crossing region of the Sona transition. The polarization without the shield was 62.6±1.7%; with the shield it was 63.7±1.1%, thus showing little improvement. Measurements varying the laser size by 200% indicated little dependence on laser size.

FARADAY ROTATION DIAGNOSTICS

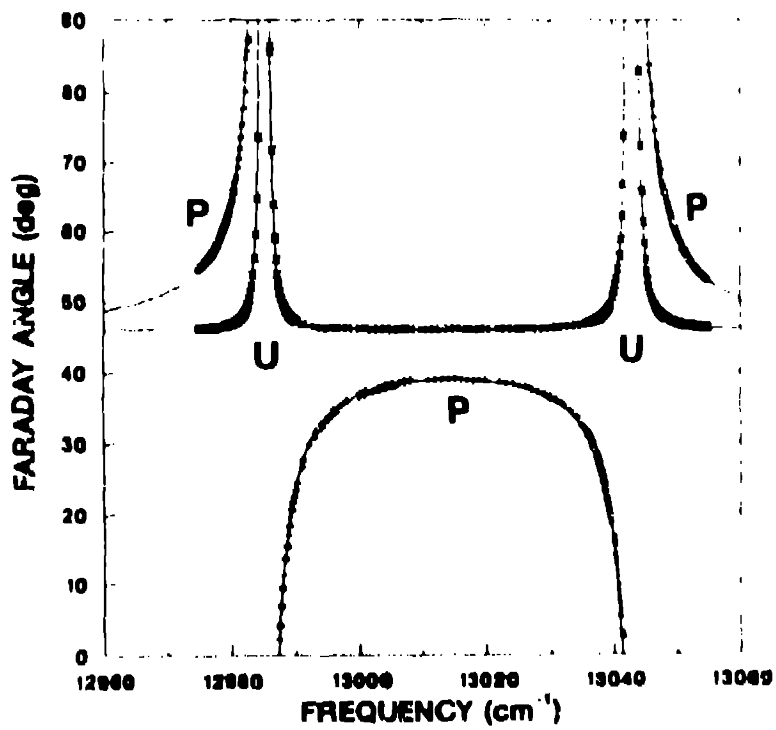

Fig. 3. Measured and calculated Faraday rotation angles for unpolarized (U) and polarized (P) K vapor. Thickness is 5.0×10^{13} cm^{-2} and polarization 72%.

Faraday rotation is a useful diagnostic for measuring the thickness and electron spin polarization of an alkali vapor. Extracting useful information from the measurements requires accurate calculations of the Verdet constant for unpolarized and polarized vapor. M. Dulick has written a computer program[6] that calculates these constants for each of the alkalis, for all probe laser frequencies, and for all magnetic fields. A copy may be obtained from the authors. Measurements with Na and K vapor at various frequencies and magnetic fields are consistent with the calculations. Figure 3 is an example of our data at 3 kG.

At the last conference[7], we described several techniques for measuring Faraday rotation. The measurements of Fig. 3 were made using the "Two-detector method". We have further developed the "Rotating $\lambda/2$ plate method" and have found it to be the method of choice. The "Rotating $\lambda/2$ plate method" gives accurate, stable, real-time measurements and does not require frequent calibration. It was used to test the accuracy and stability of the OPPIS automated spin flip over several days .

LASER FREQUENCY DISTRIBUTION

The spectral output of our Ti:Sapphire laser is narrowed by two uncoated etalons (200 GHz and 20 GHz free spectral range) to match the Doppler-broadened absorption line of K vapor (1 GHz FWHM). It consists of four or more discrete longitudinal cavity modes spaced 225 MHz apart, as shown in Fig 4a. The discrete nature of the distribution may limit the optical pumping efficiency because the mode spacing is large compared to the natural line width To test the effect of a more uniform laser spectrum, we have obtained a prototype vibrating laser cavity mirror[8]. The mirror is mounted on a high-frequency acoustic horn, which is excited by a piezo-electric modulator. This allows the laser cavity length, and hence the frequency of the cavity modes, to be modulated at 140 kHz, which is faster than the average wall collision rate (45 kHz) of the K vapor. Figure 4b shows the laser frequency distribution with the modulator on. In limited tests conducted during accelerator operations, the modulator did not affect the polarization of the beam as measured by the 800-MeV polarimeter. Further tests are needed. A larger improvement is expected for Rb vapor because the linewidth is greater.

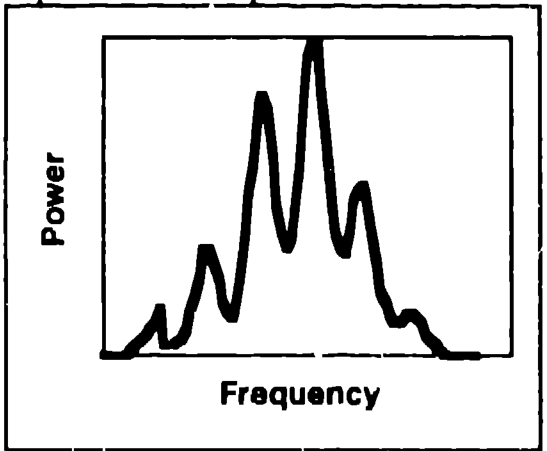

Fig. 4a. Laser Spectrum with modulator off. Laser power 3.8 W.

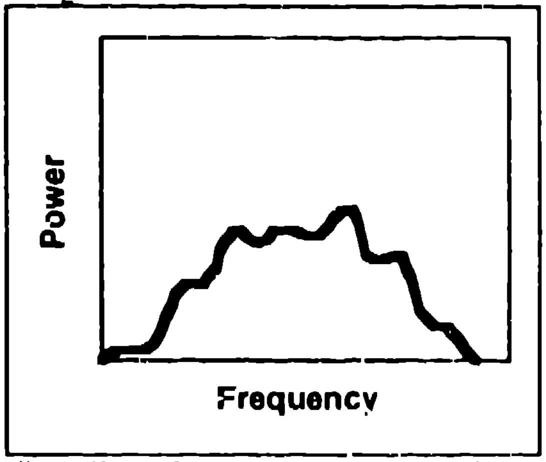

Fig. 4b. Laser Spectrum with modulator on. Laser power 3.5 W.

[1] Louis Brown, and Claude Petitjean, Nucl. Phys. A117 343 (1968)

[2] L. Buchmann, Nucl. Inst. and Meth. A301 383 (1991)

[3] We acknowledge L.J. Rybarcyk for suggesting the idea, and helpful discussions, H.E. Williams for engineering, and K.W. Jones, J. D. Wieting, W.P. Potter, F. J. Wehner, J.D. Paul, and M. McNaughton.

[4] W. Haeberli, Ann. Rev. Sci. 17 373 (1967)

[5] We measured α_4/α_3 to be 1.4. The value obtained from reference 1 was 1.6.

[6] M. Dulick, Program "Faraday.for", VAX FORTRAN 77 Version, LA-UR 91-1577, LANL (1991)

[7] D R. Swenson et al., KEK Report 90-15 A, 187 (1990)

[8] Gaylen Erbert, LLNL, L-463, PO Box 808, Livermore, CA 94551, U.S. patent 5132979